SHEAR BOND STRENGTH OF ALUMINA COATINGS

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Introduction

The coating research being conducted at the NASA Lewis Research Center has involved studies of the bond that forms between a plasma-sprayed coating and a substrate at the time of deposition. The early work concerned metallic coatings deposited on metallic substrates, and particular attention was given to improving the quality of their interfacial bond. Lately, more emphasis has been given to the study of the factors that influence the bond strength of ceramic coatings on metal substrates and the quantitative measurements of such bond strengths.

In most ceramic-metal coating systems deposited by thermal spraying, bond failure occurs when the interfacial shear stress exceeds the "bond strength". This stress condition arises because of relatively large differences in the thermal expansion coefficients and ductilities of the two components. Thus, thermal or mechanical loading causes such coatings to spall.

The measurement of the shear bond strength of alumina coatings and the factors that affect it were first investigated systematically by Moore (ref. 1). In the present report, a new test was used to study the effect of particle size distributions on the shear bond strength of plasma-sprayed alumina coatings. (A more complete description of this work is given in ref. 2.)

Materials

Four commercial alumina spray powders were used in this investigation. The powder size distribution for each is presented in figure 1 and summarized, along with the chemical analysis data, in table I.

All substrates were 1/4-inch-thick AISI 304 stainless steel.

Apparatus and Procedure

Standard commercial plasma-spraying equipment and procedures were used to deposit all coatings. Spray conditions were fixed throughout the program as follows:

[redacted]

TM X-52092

Nozzle type C
Arc amperage, A 400
Arc voltage, V 60
Plasma gas
  High purity dry nitrogen, scfh 100
  Hydrogen, scfh 15
Carrier gas
  High purity dry nitrogen, scfh 10
Power feed (65 power feed dial setting) lb/hr ....approx. 2
Torch-to-substrate distance, in. 6

The shear bond test apparatus is shown in figure 2. It consists of a 1/4-inch-substrate plate of stainless steel onto which is fastened a set of steel guide rails. The stainless-steel slider (also 1/4 in. thick) travels within these guides. This slider contains a drilled hole, 5/8 inch in diameter, to expose a fixed area of substrate that becomes the test area.

In this study, the test area was first processed either by polishing the substrate (approx. 0 rms), or by grit blasting it with the slider in place (115, 225, or 280 rms). After acetone cleaning, the slider was put back into the same position and a 0.030-inch-thick coating was deposited on the test area through the hole in the slider. During spray coating, the back of the substrate was air cooled so that the temperature, measured 0.040 inch below the test surface by an embedded thermocouple, never exceeded 360° F and averaged about 330° F for most runs. A brass shim stock shield prevented the spray particles from striking any place other than the test area.

After cooling, the shield was removed and the test assembly rigidly mounted to a test bench. A cable and a weight holder were attached to the slider, and the coating-substrate interface was dead-weight loaded in 1-pound increments until shear failure occurred.

Results

Shear bond strength data for the coatings tested are presented in table II; mean bond strengths are shown in figure 3 as a function of surface roughness. These data show that

1. The bond strengths of all coatings deposited on the polished surfaces were zero.
2. Increasing the substrate surface roughness causes an increase in the mean bond strength, but this effect appears to lessen somewhat at the higher roughness levels.
3. Those powders with a high percentage of intermediately sized particles (a more uniform particle size distribution with low percentages of fine and coarse particles) such as A and D, show higher bond strengths at any given level of surface roughness.

[redacted]

References

1. Moore, D. G.: Basic Studies of Particle-Impact Processes for Applying Ceramic and Cermet Coatings. Nat. Bur. of Standards Repts. 6259, 6453, 6544, NBS, Oct. 1958 to Sept. 1959.

2. Grisaffe, S. J.: Quantitative Analysis of the Bond Strengths of Plasma Sprayed Coatings. M. S. Thesis, Case Inst. Tech., 1965.

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TABLE I. - SPRAY POWDER CHARACTERIZATION

Powder	Suppliers' chemical analysis, weight percent	Mesh range	Size range, μ
A	97.5 Al_2O_3, 2.5 TiO_2	-200 +325	3.9 to 46: 50% < 18.8
B	98.0 Al_2O_3, remainder: Si, Fe, NaO	-200 +325	3.7 to 38.9: 50% < 8.6
C	99.49 Al_2O_3, .05 SiO_2, .1 FeO, .1 TiO_2, .35 NaO	-200 +325	7.3 to 82: 50% < 11.4
D	99.49 Al_2O_3, .05 SiO_2, .1 FeO, .1 TiO_2, .35 NaO	-35 +15 microns	3.4 to 37.9: 50% < 15.9

TABLE II. - BOND STRENGTH DATA

Powder	Roughness, rms	Mean bond strength, psi	Range, psi	Standard deviation, psi
A	280	550	443 to 695	72
B	~0	~0	----------	--
	115	265	161 to 395	76
	225	385	262 to 532	73
	280	489	325 to 700	108
C	280	506	358 to 645	106
D	~0	~0	----------	---
	115	383	323 to 510	56
	225	544	387 to 695	88
	280	586	413 to 750	86

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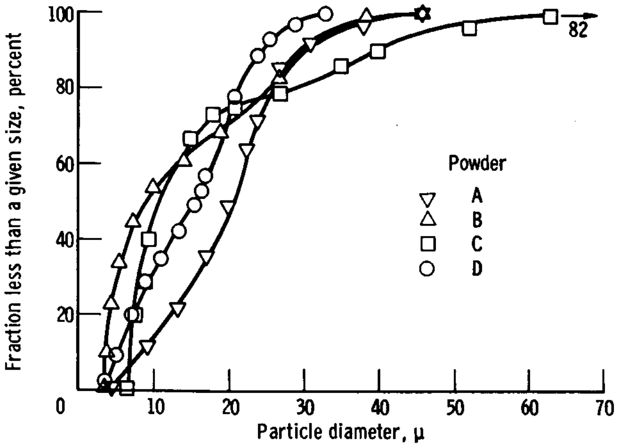

Figure 1. - Particle size distribution of four alumina spray powders.

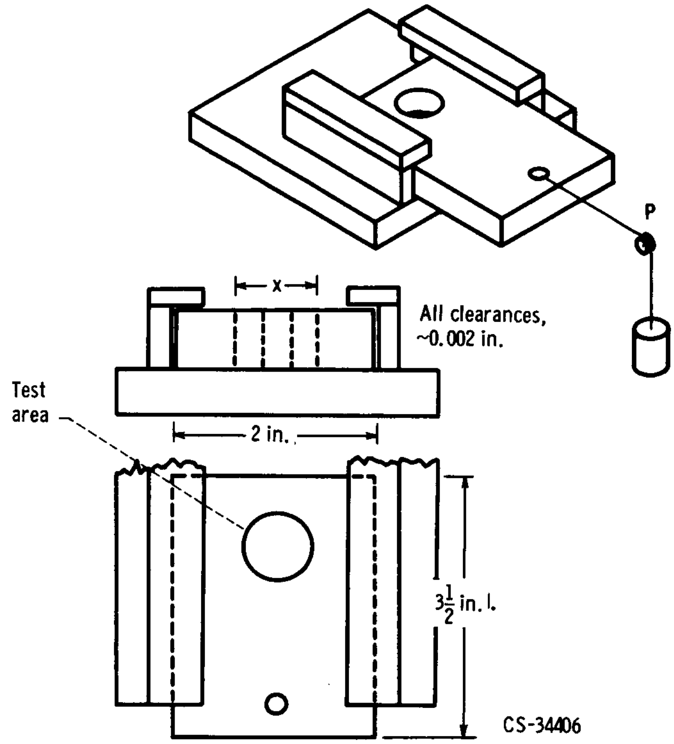

Figure 2. - Shear bond test apparatus.

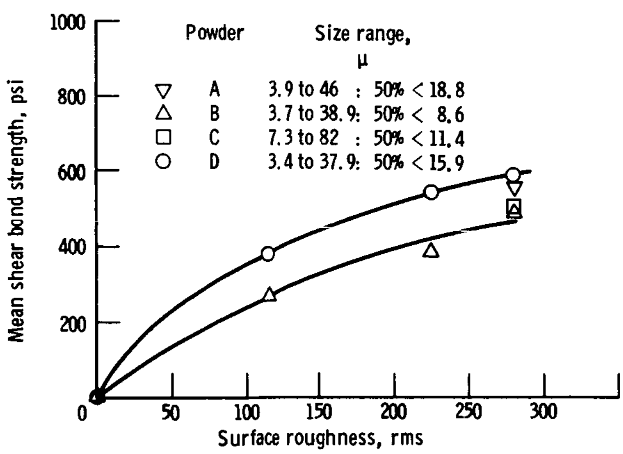

Figure 3. - Mean shear bond strength as function of surface roughness for four varieties of alumina coatings on 304 stainless steel.